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SOIL STRUCTURE OF CALCARIC AND NON-CALCARIC RENDZINAS UNDER FOREST, GRASSLAND AND ARABLE LAND

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This study aimed to quantify structural properties of rendzina soils in Serbia, and especially to determine the effect of decarbonation and different forms of land use on soil aggregate ditribution and stability. An indication of favourable soil aggregate distribution is data showing that the content of aggregates with 1-5 mm particle size, which is desirable from the agronomical viewpoint, is 50.04% on the average, while macroaggregates make 6.28-fold the sum of micro and mega aggregates. High aggregate stability is indicated by the fact that the proportion of water stable aggregates of >1 mm size ranges from 53.78 to 91.38%, i.e. 71.38% on the average.

With increasing alkalinity of calcaric rendzina soils, aggregate stability in water significantly decreases. Concerning non-calcaric rendzina soils, the proportion of fine aggregates increases as the process of decarbonation proceeds and their stability decreases. Differences in

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aggregate distribution and stability bewteen the calcaric and non-calcaric rendzina soils were not found to be statistically significant. Forest and grassland rendzinas showed no significant difference regarding structural properties. Soil tillage has significant effect on the soil structure of arable rendzinas and, compared to forest and grassland rendzinas, they have less favourable structure index and water stable aggregate content.

Key words: aggregate distribution and stability, rendzina, decarbonation, land use

INTRODUCTION

Structural development and aggregation of soil occur as part of natural pedogenetic processes and anthropogenic activities. Aggregates are secondary particles formed through combination of mineral particles with organic and inorganic substances. The complex dynamics of aggregation are the result of interaction of many factors including the environment, soil management factors, plant influences and soil properties, such as mineral composition, texture, soil organic carbon concentration, pedogenetic processes, microbial activity, exchangeable ions, nutrient reserve and moisture aviability (BRONICK and LAL, 2005).

Soil structure is an important soil property to be evaluated because it mediates many biological and physical processes in soils. For example, soil structure determines porosity and infiltration, hence water availability to plants and soil erosion susceptibility. Since soil structure also influences losses of agrochemicals, sequestration of C, and N gas losses, it is important to maintain soil structure in order to reduce the environmental impact of agricultural practices (SIX *et al*., 2000). For example, long term cultivation may cause soil structure degradation, erosion and soil fertility decrease (HAYES and CLAPP, 2001).

Aggregate distribution and stability are often used as a measure of soil structure. They are also frequently used as indicators of the effect of different management practices on soil stucture (SIX *et al*., 2000).

Rendzina is a very widespread soil type in Serbia, especially in hilly and mountainous parts of the country. In areas of smooth relief, rendzinas underlie arable land and grassland, but most such areas, and primarily those on inclined terrain, are forested. No experimental data on the structure of rendzina soils is available in this country at present. This study aimed to determined in quantitative terms the structural properties of rendzina soils in Serbia, and especially the effect of decarbonation process and different forms of land use on soil aggregate distribution and stability.

MATERIALS AND METHODS

The research sites included hillsides of Mt. Fruška gora (profiles 12 and 13), Topola and Aranđelovac environs (profiles 18-21), areas around Lajkovac and Valjevo (profiles 15-17), Sjenica-Peštar plateau (profile 11), Negotin environ (profiles 1-10) and the Niš-Pirot stretch (profiles 22-31).

On each research site, we collected samples of both the calcaric and non-calcaric variants of rendzina soil developed under all three types of land use if those were available. Calcaric rendzinas were found to be predominant on all research sites, so that more profiles of that subtype were examined than of the non-calcaric subtype. Twenty-seven soil profiles where included in our field investigation, i.e. 21 profiles of calcaric rendzinas (9 forest, 7 grassland and 5 arable land) and 6 profiles of non-calcaric rendzinas (3 forest, 2 grassland and 1 arable land). A total of 42 soil samples were collected and analysed from the A and AC horizons (where those were found).

Most of the research profiles belong to the rendzina soil type on unindurated or marly limestone, calcaric (No. 1-6, 9, 11, 18, 19, 22, 27, 28, 30 and 31), followed by rendzinas on unindurated or marly limestone, non-calcaric (No. 7, 8, 10, 16, 17, 20 and 21), while the same number of profiles (No. 12, 13, 14, 15, 23, 24 and 29) are rendzinas on marl, calcaric (according to classification proposed by ŠKORIĆ *et al*., 1985).

Table 1 presents statistical data on the basic chemical properties of the rendzina soils investigated. Carbonate content in calcaric rendzinas varies over a wide interval from 0.71 to 51.84%, soil reaction is neutral to slightly alkaline, substitutional acidity is not prominent, and pH values in KCl exceed 6.71. Non-calcaric rendzina soils are pH neutral, and substitutional acidity is weak. An adsorption complex analysis indicated a high cation exchange capacity and high base saturation.

Decarbonation processes had a considerable effect on basic chemical properties of rendzina soils, so that non-calcaric rendzinas have statistically significantly lower pH values in water (t=7.55094, p=0.000280) and KCl (t=6.05835, p=0.000917), as well as lower humus content (t=2.55016, p=0.043481) than calcaric rendzinas.

Different forms of land use have proved to exert significant effect on soil humus content. Forest rendzinas contain significanlty more humus than those under grassland (t=2.92185, p=0.015252), and especially under arable land (t=7.45738, p=0.00003), while grassland rendzinas contain significantly more humus than those under arable land (t=4.62977, p=0.000937).

Laboratory research of soil structure was done using the Savinov method - dry and wet sieve analysis **(**JDPZ, 1997). Structure index is a ratio of macro aggregates (0.25-10 mm) and a sum of micro (<0.25 mm) and mega aggregates (>10 mm).

Statistical processing was done using the StatSoft Statistka 5.0 software. Correlation analysis revealed a link between the basic soil properties and aggregate distribution and stability. T-test was employed to compare soil structure between the calcaric and non-calcaric rendzina soils, and the land use variants. Statistical significance was determined at 95% confidence level.

Table 1. - Statistical description of the chemical properties of rendzina soils

Property	Variant	n	Mean	Minimum	Maximum	Standard deviation
Humus (%)	Calcareous	33	5.54	1.87	10.77	2.48
	Non-calcareous	9	4.63	2.16	8.65	2.49
	Forest	17	7.07	2.17	10.77	2.06
	Grassland	13	5.44	2.16	9.86	2.03
	Arable	12	2.87	1.87	5.31	0.96
$CaCO_3$ (%)	Calcareous	33	12.29	0.71	51.84	13.32
pH in H_2O	Calcareous	33	7.67	7.33	7.98	0.12
	Non-calcareous	9	7.20	6.98	7.64	0.22
pH in KCl	Calcareous	33	7.00	6.71	7.58	0.21
	Non-calcareous	9	6.36	6.08	6.77	0.26
H (meq)	Non-calcareous	9	1.51	0.83	2.49	0.53
S (meq)	Non-calcareous	9	35.40	25.64	52.41	8.85
T (meq)	Non-calcareous	9	36.90	27.30	53.45	8.78
V (%)	Non-calcareous	9	95.72	93.74	98.05	1.66

RESULTS AND DISCUSSION

Using dry sieve analysis we found a highly variable distribution of the individual soil aggregate fractions in rendzina soils (Table 2). The fractions were found to be distributed in the following order by average: fraction size 10-5 mm in 22.32% (SD=10.37), 2-1 mm in 18.46% (SD=9.42), 5-3 mm in 17.06% (SD=6.29), 3-2 mm in 14.51% (SD=4.77), >10 mm in 13.23% (SD=14.31). Aggregates of 1-0.5 mm are significantly less present on the average with 6.85% (SD=4.46), micro aggregates of <0.25 mm with 4.92% (SD=4.55) and the least those of 0.5-0.25 mm with 2.19% (SD=1.65). Favorable soil aggregate distribution is best illustrated by that fact that the average content of aggregate fraction size 1-5 mm, which is desirable from the agronomical point of view, accounts for 50.04% (SD=12.74), while macro aggregates were found to be 6.28-fold (SD=3.43) higher than the sum of micro and mega aggregates.

Water stable aggregate fractions are distributed in the following order: 5-3 mm with 38.54% (SD=21.92), 2-1 mm with 24.34% (SD=11.85), 1-0.5 mm with 13.54% (SD=5.10), <0.25 mm with 12.94% (SD=4.79), 3-2 mm with 8.41% (SD=3.73) and 0.5-0.25 mm with 2.15% (SD=0.83). High soil aggregate stability is evident from the fact that water stable aggregates >1 mm account for 53.78-91.38%, or the average 71.38% (SD=9.46).

Statistical data analysis showed that non-calcaric rendzina soils contain more mega aggregates on the average, as well as the 10-5 mm particle fraction, while the content of other fractions of macro aggregates is lower or closer by comparison to calcaric rendzinas. Non-calcaric rendzinas also have lower average contents of micro aggregates, as well as the total aggregate fraction 1-5 mm. Soil agreggate distribution was found to be more favourable in calcaric rendzinas as their structure index is 6.74 on the average, compared to 4.58 in non-calcaric rendzinas. The difference is thus evident but without statistical significance.

On the other hand, non-calcaric rendzinas, compared to calcaric, have lower average contents of coarse fractions of water stable aggregates >2mm, as well as more micro aggregates and less aggregates of 0.25-2 mm (Figure 1). The sum of water stable aggregate fractions >1 mm is lower on the average in non-calcaric than calcaric rendzina soils. However, the difference was again insignificant statistically.

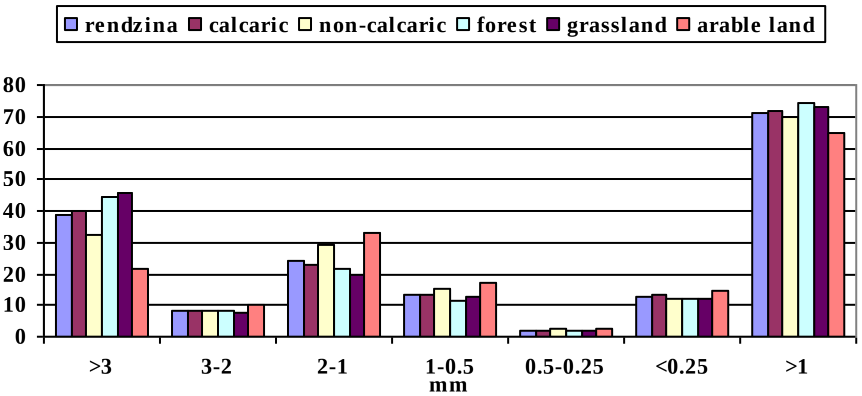

Figure 1. - Water stable aggregate distribution of rendzina soils (mean in %)

These differences in soil aggregate distribution result primarily from differences in particle size distribution and chemical properties of the calcaric and non-calcaric rendzina soils. According to CUPAĆ *et al*., (2006), non-calcaric rendzinas contain lower average amounts of coarse fragments and more colloidal clay than calcaric rendzina soils. Correlation analysis showed that an increase in clay content is accompanied by significant increase in mega aggregates and 10-5 mm fraction, while aggregates of <3 mm decrease. Concerning water stable aggregates, a correlation was found in non-calcaric rendzina soils, in which aggregates of >3 mm increase considerably with an increase in colloidal clay content, while aggregates of <2 mm decrease. Heavier texture created conditions for the formation of coarse soil aggregates in non-calcaric rendzina soils, but their water stability is lower compared to aggregates in the calcaric rendzina soils, and the reason for this is to be sought in soil chemical properties.

In calcaric rendzinas that are neutral to slighly alkaline, a pH increase in water and KCl is accompanied by a decrease in water stable aggregates of >3 mm and increase in all fractions of <3 mm, while the total fraction of >1 mm significantly decreases. The increase in alkalinity in calcaric rendzina soils is therefore followed by a significant decrease in water aggregate stability. The reason for this is suggested in a report by KUŽNICKI and SKLODOWSKI (1976), who had found that in Polish rendzinas with high active carbonate contents, the newly-formed humic acids were fast-binding, i.e. neutralized by Ca ions, and were weakly polymerized and probably weakly bound to mineral soil fractions.

In non-calcaric rendzina soils, soil reaction is significantly lower than in calcaric rendzinas. In non-calcaric rendzinas, which are pH neutral and their substitutional acidity weak, pH increase in water and KCl is accompanied by increase in the content of water stable aggregates of >2 mm and decrease in the content of <2 mm fractions. Distribution of the total fraction of water stable aggregates >1 mm increases with pH increase. With an increase in soil base saturation the aggregates of >3mm increase while distribution of the remaining fine aggregates decreases, and similarly the water stable aggregates of >2mm increase and the remaining fine aggregates decrease. Therefore, as the process of decarbonation proceeds in non-calcaric rendzina soils, the portion of fine soil aggregates increases and their water stability decreases. In a soil aggregation process, the important influence is their chemical reactivity controlled by the pH of soil dilution, acting on electrostatic charge of humic acids (RIZZI *et al*., 2004).

Differences in aggregate distribution and stability between the calcaric and non-calcaric rendzina soils bear no statistical significance, and this is only logical as decarbonation effected a soil pH decrease, even though it still had a high case saturation degree, especially Ca^{2+}, which is a known and most important coagulator responsible for aggregation process and aggregate stability.

Soil humus content was found to have significant influence on aggregate distribution and stability. With increasing humus content the portion of mega aggregates (>10 mm), as well as all aggregates of <3 mm and structure index, showed a statistically significant decrease. Regarding water stable aggregates, the increasing humus content is accompanied by increasing participation of >3 mm aggregates, while all those <2 mm decreased. The total water stable aggregate fraction >1 mm increased with the increase in humus content in rendzina soils.

Differences in humus content were especially evident between the rendzina soils under different land use variants. As mentioned before, forest and grassland rendzinas contain statistically significantly more humus than arable land rendzinas, which was found to have direct effect on soil aggregate distribution and stability. Structure index for the grassland and forest rendzinas was thus significantly higher than for arable land rendzina (t=2.33304, p=0.044525 and t=3.37578, p=0.007053, respectively). Concerning differences in water aggregate stability, grassland rendzinas contain significantly more coarse aggregates >3 mm than arable rendzina (t=4.37838, p=0.001381), while the content of fractions 2-1 and 1-0.5 mm was found to be higher in arable than in forest rendzina (t=2.34260, p=0.043833 and t=2.88472, p=0.018039) and especially grassland rendzina (t=4.16656, p=0.001929 i t=3.30050, p=0.008007). Total water stable aggregates >1 mm were found to be significantly higher in forest and grassland than in arable rendzina (t=2.33304, p=0.044525 and t=2.71316, p=0.021815, respectively).

Arable rendzina soils therefore have more unfavourable structure index and aggregate water stability. As it was mentioned in the introductory section, cultivation affects soil structure in several different ways, and the effects can be more or less direct.

Tillage disrupts soil aggregates, compacts soil and disturbs plant and animal communities that contribute to aggregation, and lowers soil organic matter, CEC, nutrients, microbial activity and fungial activities that contribute to aggregation (PLANTE and MCGILL, 2002). According to SIX *et al*., (2000), reduced aggregation on arable land results from soil cultivation, which has several indirect effects on aggregation: (i) Tillage brings subsurface soil to the surface where it is then exposed to wet-dry and freeze-thaw cycles and is subjected to raindrop impact, thereby increasing the susceptibility of aggregates to disruption; (ii) Plowing changes soil condition (e.g., temperature, moisture and aeration) and increases decomposition rates of litter; (iii) Proportion of the microbial biomass composed of total fungi and mycorrhizal fungi is generally higher in virgin soils than in arable soils, and it has been observed that fungi contribute to macro aggregate formation and stabilization.

There have been reports from a considerable number of studies on the influence of organic matter as a crucial cementing agent on soil structure properties. Soil tillage reduces humus content by changing the quality of organic residues and reducing their annual input in soil. Furthermore, tillage increases soil aeration and thereby speeds up the process of mineralization of litter and humus in soil. SWIFT (2001) observed a usually good correlation between soil organic matter content and aggregate stability for soils with similar textures and mineralogical contents, while CHENU et al. (2000) reported that soil organic matter associated to clay minerals gave them increased hydrophobicity. Increased water stability of aggregates could be ascribed to better resistance to slaking, through increased hydrophobicity of the aggregates, and to increased internal cohesion of the aggregates. HALLETT *et al*. (2001) found water repellency to be a fundamental physical property of soil with implications for the resistance of soil structure against discruption by wetting, bypass flow and surface runoff. In their study, cultivation was found to cause a twofold decrease in repellency, while pasture soil had a repellency value that was three times higher than plowed soils. The data presented by KONG *et al*. (2005) also indicate that aggregate stability in

Mediterranean agricultural lands (10 cropping systems) increased linearly with increase in organic matter input in soil.

The contrasting roles of soil organic matter in preserving soil structure stability are best illustrated by a report by D'ACQUI *et al*. (1999), who investigated the influence of organic matter on aggregate dispersion and characterized the organic fractions involved in destabilizing or maintaining microstructure in tropical soils. After removal of organic matter (by low-temperature ashing) from a cultivated soil the dispersion of aggregates decreased, which could be ascribed to the removal of negatively charged, low molecular weight humic substances. These substances, formed by degradation of organic matter due to cultivation, may destabilize the microstructure of soil under specific physico-chemical conditions. Conversely, increase in dispersion of the uncultivated soil appeared to be caused by the removal of aliphatic hydrophobic compounds. These aliphatic compounds, which were more abundant in the uncultivated soil, protect aggregates from the action of water (slaking and dispersion).

In the future, in order to increase aggregation, soil management should aim at increasing primary plant production and the amount of carbon input into the soil, and decreasing disturbances and the rate of carbon loss by processes such as decomposition and erosion (BRONICK *at al*., 2005). In this context, improved management practices include tillage methods, residue management, amendment, soil fertility management and nutrient cycling (BLANCO-CANQUI *et al*., 2005; BRONICK *at al*., 2005; FRANZLUEBBERS et al., 2000; GALE *et al*., 2000a; 200b; IMBUFE *et al*., 2005; KOUTIKA *et al*., 2005; MIKHA AND RICE, 2004; SIX *et al*., 2002; WRIGHT AND HONS, 2005).

CONCLUSION

A very favorable soil aggregate distribution in the rendzina soils investigated is indicated by data showing that soil aggregates 1-5 mm, i.e. the most desirable aggregates from the agronomical viewpoint, account for the average 50.04%, and that macro aggregates make 6.28-fold the sum of micro and mega aggregates.

High aggregate stability is indicated by the fact that water stable aggregates >1 mm account for 53.78-91.38%, or the average 71.38%.

With increasing alkalinity of calcaric rendzina soils their aggregate water stability significantly decreases.

In non-calcaric rendzinas, as the process of decarbonation proceeds the proportion of fine aggregates increases, while their water stability decreases.

The differences in soil aggregate distribution and stability between calcaric and non-calcaric rendzina soils were not found to bear statistical significance.

Forest and grassland rendzinas showed no significant difference regarding structural properties. Soil tillage was found to affect significantly the soil structure of arable rendzina, so that, compared to forest and grassland rendzinas, they have more unfavorable structure index and aggregate water stability.

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STRUKTURA KARBONATNIH I IZLUŽENIH RENDZINA POD ŠUMAMA, TRAVNJACIMA I NJIVAMA

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Izvod

Renzina je tip zemljišta veoma rasprostranjen u Srbiji, a podaci o njenim stukturnim osobinama su samo opisni. Struktura zemljišta je veoma važna osobina koja utiče na mnoge biološke i fizičke procese u zemljištu. Cilj ovog rada bio je da utvrđivanje kvantitativnih podataka o stukturnim osobinama rendzina u Srbiji, posebno uticaja procesa izluživanja i različitih načina korišćenja zemljišta (šuma, travnjaci i njive) na veličinu i stabilnost strukturnih agregata. Veličina strukturinih agregata u rendzinama je veoma povoljna o čemu svedoče podaci da sadržaj, s agronomske tačke poželjne frakcije veličine 1-5 mm, u proseku iznosi 50.04%, a makroagregata ima 6.28 puta više u odnosu na zbir mikro i megaagregata. O visokoj otpornosti strukturnih agregata u vodi govori podatak da su vodootporni strukturni agregati veći od 1 mm zastupljeni sa 53.78 do 91.38%, a u proseku sa 71.38%. S povećanjem alkalnosti karbonatnih rendzina značajno se smanjuje vodootpornost strukturnih agregata. Unutar izluženih rendzina s napredovanjem procesa izluživanja dolazi do povećanja udela sitnijih strukturnih agregata i smanjenja njihove otpornosti prema vodi. Razlike u distribuciji i stabilnosti strukturnih agregata između karbonatnih i izluženih rendzina nisu statistički značajne, što je i logično s obzirom da su procesi izluživanja uticali na snižavanje pH zemljišta, ali je ono i dalje ima visok stepen zasićenosti bazama, naročito Ca^{2+} koji je, kao što je poznato, jedan od najznačajnijih koagulatora odgovornih za obrazovanje strukturnih agregata i njihovu stabilnost. Šumske i travnjačke rendzine ne razlikuju se značajno po strukturnim osobinama. Obrada zemljišta značajno je uticla na strukturu njivskih rendzina, tako da one u poređenju sa šumskim i travnjačkim imaju nepovoljniji koeficijent strukturnosti i manju stabilnost strukturnih agregata. Obrada zemljišta, pored direktnog usitnjavanja strukturnih agregata, na strukturu utiče i indirektno menjanjem temperature, vlage i aeracije i time pojačava proces mineralizacije organskih ostataka (čija je količina ionako manja nego u devičanskim zemljištima) i menja sastav zemljišne mikroflore, što se direktno odražava na formiranje i stabilnost makroagregata u zemljištu. Da bi se zaustavio proces degradacije i unapredio proces obrazovanja strukturnih agregata i njihova stabilnost potrebno je u procesu poljoprivredne proizvodnje povećati priliv organskih ostataka u zemljište, smanjiti gubitke organskog ugljenika iz zemljišta erozijom i dekompozicijom, što se može postići pravilno organizovanom agrotehničkom praksom.

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